

C. P. Steinmetz and E. F. W. Alexanderson: Creative Engineering in a Corporate Setting

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Abstract—A Consulting Engineering Department was organized by the General Electric Company in 1910. It was designed to complement the General Electric Research Laboratory through a focus on creative engineering rather than basic science. The Department was conceived and directed during its early years by C. P. Steinmetz. It continued under the able leadership of a Steinmetz protégé, E. F. W. Alexanderson, until its identity was finally lost during a reorganization in 1951. The Department produced numerous innovations in communications, electronics and power engineering, including a world radio system that provided the technological basis for a new corporation, the Radio Corporation of America, founded in 1919. The history of the Department and the philosophy articulated by Steinmetz and Alexanderson are considered from the perspective of recent studies of the nature of science and technology and their interaction.

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I. C. P. STEINMETZ

A CONSULTING ENGINEERING Department staffed by a select group of engineers was established at the Schenectady works of the General Electric Company in 1910. The new department was conceived and directed by the almost legendary Charles Proteus Steinmetz. It was designed to complement the older and already famous General Electric Research Laboratory (GERL) through a focus on creative engineering rather than science. After surviving the disruptive impact of the World War I and the untimely death of Steinmetz in 1923, the internal consulting tradition was continued under the leadership of E. F. W. Alexanderson, a protégé of Steinmetz and charter member of the Consulting Department. Alexanderson's Consulting Department was continued until his retirement after World War II when its identity was lost during a reorganization. During the approximately four decades of its existence the Consulting Department was the source of numerous significant technical innova-

tions that derived from the "interdisciplinary" interests of its members in communications, electronics, and power engineering.

Steinmetz would be an appropriate subject for a paper on needs and opportunities for research. When his definitive biography is written, it should contribute greatly to our understanding of differences between science and engineering, the process of professionalization of engineering, and the question of social responsibility of engineers. Space limitations permit including only highlights from his *vita*e that relate to his role in the creation and early direction of the Consulting Engineering Department.

Steinmetz was born in Breslau, Germany, in 1865 and suffered from an unfortunate physical deformity from birth. He had completed work on a doctorate in mathematics at the University of Breslau in 1888 when the prospect of being arrested for suspected subversive activities caused him to flee the country without the degree. After a year in Switzerland where he studied engineering at the Polytechnic Institute in Zurich, Steinmetz came to the United States. His first job was with a small electrical manufacturing firm of Eickemeyer and Osterheld in Yonkers, NY.

Steinmetz's professional reputation was enhanced greatly by two remarkable papers on magnetic hysteresis that he presented before the American Institute of Electrical Engineers (AIEE) in 1892. Almost immediately, the Eickemeyer and Osterheld Company was acquired by the newly formed General Electric Company with Steinmetz joining its Calculating Department. During his first year with G.E., Steinmetz presented a classic paper at the International Electrical Congress in Chicago that introduced the powerful method of complex-number algebra for the analysis of alternating current circuits and machines. His rapid rise to prominence in American engineering was confirmed by his election as AIEE president in 1901.¹

Steinmetz was one of the four who proposed the establishment of the GERL in 1900.² He declined the opportunity to become head of the new laboratory for reasons that remain somewhat speculative. The argument that he was too "individualistic" or preferred to avoid administrative responsibility may have some substance but did not prevent his agreeing to head the Consulting Department a few years later. It seems more likely that Steinmetz considered himself an engineer rather than a research scientist and felt that this made him unsuitable for the position.³

The creation of the Consulting Engineering Department brought formal recognition of the interdepartmental activities that Steinmetz, Alexanderson and a few others at G.E. had practiced informally and that no existing organizational structure encompassed. Steinmetz evidently intended to make the Consulting Department serve as a sanctuary for a few engineers who shared his philosophy and did not fit well in narrowly specialized departments or the GERL. For such engineers the

new department would furnish the technical assistants and other resources needed to solve problems that interested them or even to develop novel power or communications systems to the commercial stage. An informal but effective apprentice system was soon implemented to aid in the selection of recruits for the Department. It provided an attractive alternative for engineer-inventors who might otherwise have left the company to become independent consultants or entrepreneurs.

The organization of the Consulting Department came at a time when there was great interest and enthusiasm for Frederick Taylor's system of "scientific management." This suggests that Steinmetz may have perceived his new department as a way to enhance the autonomy and status of corporate engineers, an end that Taylor hoped to gain through preemption of the managerial function.⁴

Steinmetz gave a rationale for the Consulting Department and how it should function in a memorandum written in 1912. He stated that it had been organized to consult with and advise other departments on unusual phenomena, design requirements or troubles encountered. The Department would also provide assistance to customers and would investigate phenomena or problems of general interest to the electrical engineering profession. Steinmetz emphasized that this diversity of activities necessitated a different kind of organization than the "autocratic" system employed by more traditional engineering departments. Rather than having projects assigned by the Department Head, each member of his department would generally choose his own work and be responsible for the methods used and the results.

Steinmetz stated that the only limitation was that the subject matter be potentially useful to the Company but that this was to be interpreted broadly. For example it would be acceptable to conduct an investigation of corona discharge that would be of value to the power industry but only indirectly to G.E. He noted that the almost complete independence of the engineers of his department made it necessary to have an administrative and financial organization to prevent disintegration into isolated units. However he mentioned that he had assigned these functions to Mr. Hayden in order that the consulting engineers be able to "devote all our time and energy to engineering."

Steinmetz instituted a regular routine for the diffusion of information among the Department's members although he apologized for the inconvenience since they were all so busy with their work. He requested that each engineer write a monthly report that would be a self-contained statement of the history, objectives, method and results on each project. These reports were to be kept on file so that all could stay informed. Steinmetz noted that the periodic retrospective reviews might turn up valuable information that might otherwise be overlooked. In addition, Steinmetz stated that he would try to be available for a few minutes each morning and, by appointment, for more extended discussion with individual members in the afternoon.

Members of the Consulting Department were urged to participate actively in professional engineering societies both to enhance their professional reputations and to keep them abreast of important developments outside the G.E. Company. Steinmetz encouraged them to publish the results of

¹ For biographical information on Steinmetz, see J. W. Hammond, *Charles Proteus Steinmetz*. New York: Century Company, 1924; *National Cyclopaedia of American Biography*; "Charles Proteus Steinmetz," *IEEE Spectrum*, vol. 2, pp. 82-95, Apr. 1965.

² K. Birr, *Pioneering in Industrial Research*. Washington, D.C.: Public Affairs Press, 1957, pp. 28-33. The others involved were E. W. Rice, A. G. Davis and E. Thomson.

³ *Ibid.*, p. 32. Also see an unpublished speech by Alexanderson "Research and engineering at G.E.," Oct. 7, 1948, Alexanderson Papers, Union College Archives, Schenectady, N.Y. (Hereafter cited as *AP*.)

⁴ E. T. Layton, Jr., *Revolt of the Engineers*. Cleveland, OH: Case Western Reserve Univ. Press, 1971, p. 139.

their research quickly after adequate patent protection had been obtained.⁵

II. E. F. W. ALEXANDERSON

The career pattern of Ernst F. W. Alexanderson exemplified the creative engineering tradition that Steinmetz hoped to establish at G.E. Alexanderson's own achievements provided persuasive evidence of the value of the Consulting Department in its early years, and he was largely responsible for its survival after the passing of Steinmetz. The two men differed somewhat in style and professional interests, but they shared a deep conviction that the activities of the internal consultants were essential in maintaining the Company's technological leadership in the industry.

Alexanderson's education and early experience prepared him well for membership in the Consulting Department. He was born in Sweden in 1878 and received an electrical engineering degree from the Royal Technical University in Stockholm in 1900. He then spent a year at the famous engineering school in Charlottenburg in Germany. While there he encountered a book by Steinmetz on alternating current phenomena and decided to go to America in the hope of working under Steinmetz. Alexanderson arrived in Schenectady early in 1902 and, after an interview with Steinmetz, embarked on what would become a 50-year career at G.E. Alexanderson made his first patented invention early in 1904.⁶ Steinmetz was on hand when the invention, a self-excited alternator, made its initial trial run.⁷

Late in 1904, Alexanderson was assigned to work on a challenging developmental project that Steinmetz had begun but no longer cared to pursue. The project was to design a radio-frequency alternator for Reginald A. Fessenden of the National Electric Signalling Company (NESCO).⁸ The assignment had unforeseen but far-reaching consequences for Alexanderson, the Consulting Department and the American radio communications industry.

The radio alternator project provided Alexanderson with valuable experience as a systems engineer with responsibility for orchestrating the activities of many men and departments at G.E. It brought him numerous outside contacts with other companies, university professors and military communications specialists. During the project Alexanderson developed a close working relationship with Irving Langmuir and other scientists at the GERL and became a conduit for the transfer of ideas and apparatus between it and the engineering departments. This project also established Alexanderson's lifelong pattern of concentration of inventive effort at the interface between electric power, radio and electronics.

The creative ferment that existed during the early years of the Consulting Department may be illustrated by a cluster of events that followed the completion of the first standardized

version of the Alexanderson radio alternator.⁹ Alexanderson and Professor A. E. Kennelly of Harvard University used the new alternator to investigate the physiological tolerance of the human body to high-frequency current and reported their findings in 1910.¹⁰ Major George O. Squier of the Army Signal Corps¹¹ obtained one of the alternators and used it in experiments on multiplex telephony described at an AIEE meeting in 1911.¹² Alexanderson used the alternator to measure the high-frequency properties of iron and reported his findings at an AIEE meeting in November 1911. Steinmetz whose own reputation had largely derived from a similar investigation of iron losses at low frequencies attended this meeting and expressed his delight with the new data.¹³

Alexanderson's experiments in trying to adapt the radio alternator to amplify telephonic currents led to one of his major inventions, the magnetic amplifier, early in 1912. This device later became an integral part of his long-distance radio system.¹⁴ John Hays Hammond, Jr., a wealthy young wireless enthusiast, purchased two of the radio alternators for use in experiments with radio-controlled boats and torpedoes. This led to a visit by Alexanderson to Hammond's laboratory in Gloucester in October 1912. Alexanderson informed Hammond of his magnetic amplifier and learned of recent experiments on the "ion controller" or audion by one of Hammond's assistants. This marked the genesis of Alexanderson's interest in electronic amplifiers and tuning by geometric progression. The convergence of two threads of amplifier research had a dramatic sequel.¹⁵

Alexanderson obtained an audion from Hammond and sought the assistance of the GERL whose researchers possessed the skills and instrumentation needed to convert the device into a reliable and efficient amplifier. Alexanderson's motivation was the engineering problem of developing a more selective and sensitive radio receiver that would overcome bothersome interference. An unanticipated consequence of this episode was to shift the emphasis of the GERL from incandescent lamps to electronic devices. A new high-vacuum tube made at the GERL was used to amplify signals received from Alexanderson's alternator in an exciting experiment by Langmuir and Alexanderson on May 14, 1913. Geometric tuning with a two-stage amplifier was demonstrated a few days later.¹⁶

Alexanderson joined the recently organized Institute of Radio Engineers (IRE) in 1913 and presented a paper in December on dielectric hysteresis at radio frequencies. Once

⁹ This alternator had a rating of 2 kW at 100 kilohertz. See E. F. W. Alexanderson, "Alternator for one hundred thousand cycles," *Transactions AIEE*, vol. 28, pp. 399-412, 1909.

¹⁰ A. E. Kennelly and E. F. Alexanderson, "The physiological tolerance of alternating current strengths up to frequencies of 100,000 cycles per second," *Electrical World*, vol. 56, pp. 154-156, 1910.

¹¹ See paper by Clark in this issue.

¹² George O. Squier, "Multiplex telephony and telegraphy by means of electric waves guided by wires," *Transactions AIEE*, vol. 30, pp. 1617-1665, 1911.

¹³ E. F. W. Alexanderson, "Magnetic properties of iron at frequencies up to 200,000 cycles," *Trans. AIEE*, vol. 30, pp. 2433-2448, 1911.

¹⁴ Alexanderson to A. G. Davis, January 19, 1912, AP. This letter had an attached data sheet entitled "Magnetic amplifier." Alexanderson had used a modified winding on an old transformer for the "crucial experiment."

¹⁵ Hammond to Alexanderson, Sept. 25, 1912 and Oct. 20, 1912, Hammond Papers, Library of Congress, Washington, DC.

¹⁶ The first audion arrived at the GERL in early February. See Alexanderson to L. A. Hawkins, Feb. 4, 1913, AP. The initial test of a radio frequency amplifier was reported in Alexanderson to M. W. Sage, May 14, 1913, AP.

⁵ This Steinmetz memorandum entitled "Organization of consulting engineering department and of laboratories connected therewith," dated July 10, 1912 was located among the Nixdorff Papers, Union College Archives, Schenectady, NY.

⁶ The invention was discussed in a letter from Alexanderson to E. J. Berg, April 25, 1904, AP. During his career, Alexanderson received about 350 patents.

⁷ Alexanderson to Steinmetz, December 30, 1904, AP.

⁸ Steinmetz had designed a high-frequency alternator for Fessenden in 1901. Its frequency and power output had been too low to satisfy Fessenden. Steinmetz to Fessenden, July 16, 1901, Clark Papers, Box 264, Electrical History Archive, National Museum of History and Technology, Washington, DC.

again he was following in the footsteps of Steinmetz who had investigated dielectric hysteresis in the early 1890's but at power frequencies.¹⁷ In his paper, Alexanderson explained how his new data might be used in the design of high-frequency apparatus that had so far tended to be "empirical in the extreme."¹⁸

Soon after this paper was presented, Alfred N. Goldsmith, Editor of the PROCEEDINGS OF THE IRE and a professor at the City College of New York, ordered a radio alternator and magnetic amplifier for use in experiments at his college laboratory. Alexanderson soon arranged to have Goldsmith retained by G.E. as an outside consultant on radio receivers thus taking full advantage of Goldsmith's strategic position in the radio engineering profession.¹⁹ Alexanderson also persuaded various members of the GERL including Langmuir to join the IRE and present papers on their research.²⁰

The outbreak of war in Europe in 1914 led to an accelerated program at G.E. to perfect a more powerful 200kW radio alternator and eventually to establishment of a trans-Atlantic station at New Brunswick. This station was used to transmit President Wilson's 14 point ultimatum directly to Germany in October 1918. It also was used to maintain direct communication with the *George Washington* when President Wilson went to Europe following the armistice. The dramatic success of the new radio system was a tribute to Alexanderson's abilities as a technological entrepreneur as well as to his own inventiveness.²¹ During the war he coordinated the activities of at least five teams of scientists and engineers who were assigned problem areas related to the overall system.²²

The Alexanderson alternator at the New Brunswick station provided the technological basis for creation of a world-wide radio system by a new corporation spawned by G.E. with encouragement from the U.S. Navy, the Radio Corporation of America (RCA) in 1919. Alexanderson was named as the first Chief Engineer of RCA while continuing to work part time at G.E. By 1924, eighteen Alexanderson radio alternators were installed in various parts of the world including stations in England, Sweden, Poland, and Hawaii. The hub of the new world network was a station known as Radio Central located on Long Island. The significance of the shift of the center of world communications from London to New York was the theme of a speech by David Sarnoff in 1922.²³

III

Soon after completion of the radio-alternator installations, Alexanderson resigned as Chief Engineer of RCA to resume his creative engineering activities at G.E. By now the old

Consulting Engineering Department had lost its separate identity through a merger with the Standardizing Department in 1919. However Alexanderson was named head of the Radio Consulting Department which was subsequently renamed as the Consulting Engineering Department in 1928.²⁴ His reasons for giving up a high-prestige administrative position for the comparative anonymity of an internal consulting engineer were revealed in a letter written in 1926. Alexanderson stated that the creative instinct was "an all dominating passion" for a few engineers who did not wish to become executives. He compared this passion to that felt by creative artists or writers.²⁵ During the next 25 years, Alexanderson demonstrated his creativity repeatedly with a steady stream of innovations embracing telecommunications, control systems, power electronics and high-voltage power transmission.

Alexanderson became more outspoken on the subject of creative engineering and how it might best be fostered after his tenure at RCA. In a letter to Gerard Swope in 1929, he argued that the coordination of research by several departments could best be achieved through informal personal contact rather than by committees with fixed membership.²⁶ In a speech delivered in 1933, Alexanderson stressed that G.E. engineers received great benefit from being in constant communication with scientists at the GERL. He suggested that the most important function of engineering research was to explore new fields and try to foresee directions that would lead to the industries of the future.²⁷

In 1936, Alexanderson responded to a proposal to place a few young scientists in engineering departments at G.E. He stated that if this were done it should be understood clearly that a young physicist would be expected to work as an engineer and not as a physicist. He advised that they be started out in the testing department in order to gain engineering experience. Otherwise he thought that they might end up with a group of theorists who were neither scientist nor engineer and do more harm than good.²⁸

On another occasion, Alexanderson complained bitterly about G.E. having agreed to give RCA exclusive rights to develop radio-related applications of electronics calling it a "paralyzing policy." He expressed his own conviction that contacts between radio and power engineering would lead to important inventions and to the development of new and unanticipated systems or products.²⁹

In a letter to the Company President in 1941, Alexanderson drew a distinction between systems engineering and apparatus engineering and stated that the best creative talent gravitated to the former. He continued that apparatus engineering tended to be more attractive to business-oriented individuals who were motivated by the prospect of immediate cash return. He noted that there was generally a lag of the order of ten years before a return was realized from the work of the creative systems engineer. He stressed the importance of giving the systems engineer a prominent place in the Company organization.³⁰ Alexanderson also called attention to the need to en-

¹⁷ Alexanderson described his experimental set up and asked Steinmetz for comments in a letter dated Oct. 30, 1913, *AP*. See also C. P. Steinmetz, "Dielectric hysteresis—The law of energy in a dielectric medium under alternating electrostatic strain," *Electrical Engineer*, vol. 13, pp. 272-273, 1892.

¹⁸ E. F. W. Alexanderson, "Dielectric hysteresis at radio frequencies," *Proc. IRE*, vol. 2, pp. 137-157, 1914.

¹⁹ Alexanderson to Goldsmith, March 29, 1914, *AP*. Goldsmith later built a receiver based on a design of E. H. Armstrong for use in the G.E. system.

²⁰ Alexanderson to Goldsmith, Sept. 24, 1915, *AP*.

²¹ For a discussion of the creation of the Alexanderson transoceanic system and the events that led to the formation of RCA see J. E. Brittain, "The international diffusion of electrical power technology, 1870-1920," *J. Economic History*, vol. 34, pp. 108-121, Mar. 1974.

²² See Alexanderson's memorandum "Organization of radio development and work," April 1, 1916, *AP*.

²³ Sarnoff's speech entitled "Radio: Its commercial and social influence," was delivered before the New York Electrical Society, Nov. 23, 1922. A transcript is included in the Clark Papers, (cf. footnote 8).

²⁴ The various name changes were discussed by Alexanderson in a memorandum stimulated by the consolidation of the General Engineering Lab and the Consulting Engineering Lab in 1945, *AP*.

²⁵ Alexanderson to E. H. Felix, Dec. 4, 1926, *AP*.

²⁶ Alexanderson to Swope, March 29, 1929, *AP*.

²⁷ The transcript of a speech prepared for a meeting of radio dealers is dated Sept. 19, 1933, *AP*.

²⁸ Alexanderson to M. M. Boring, October 29, 1934, *AP*.

²⁹ Alexanderson to R. C. Muir, Dec. 21, 1937, *AP*.

³⁰ Alexanderson to C. E. Wilson, May 21, 1941, *AP*.

courage teamwork between older and younger engineers wherein the young associate would contribute knowledge of the latest technical developments and the older man experience and imagination.³¹

In his Edison Medal Address in 1945, Alexanderson discussed the role of creative engineering in the social order. He thought it a paradox that it seemed to require a war to permit creative talent to function fully. He cited William James' search for a moral equivalent of war and suggested that what was needed were more engineers like Edison and Marconi who could create new industries. As attractive possibilities for the future, Alexanderson mentioned a search for new energy sources and the electrification of railroads.³²

A reorganization that included a merger of Alexanderson's Consulting Department with the General Engineering Laboratory provided the occasion for a speech on the history of the internal consulting tradition. Alexanderson credited A. G. Davis with the formulation of the central principle that creative engineers must be the leaders and the business organization followers. He recalled having learned from W. L. R. Emmet that the whole works of the Company could be used as a laboratory by an imaginative engineer. Alexanderson concluded that he wanted to pass on to a new generation a tradition that was vital to the Company. This was "the leadership of engineers who are free to set their own pace and use their own judgment."³³

Alexanderson defined creative engineering as an endeavour that linked science and engineering and that Steinmetz had come to symbolize. He stated that creative engineers and scientists were of similar temperament but that the character of the two professions were so different that their organization and responsibilities must be kept separate. He noted that Steinmetz had recognized this and had chosen to remain an engineer even though he had helped establish a laboratory for scientific research. Alexanderson stated that he had enjoyed close contacts with the GERL but had also remained an engineer. He noted that important inventions had often followed an exchange of ideas between scientists and engineers.³⁴

In what amounted to a valedictory statement in 1951, Alexanderson discussed the history and philosophy of the internal consulting tradition and how it might be continued. He suggested that the evolution of G.E. from an innovative pioneering organization to an organization oriented toward manufacturing and sales posed a serious threat to the creative engineering tradition. However he thought that the General Engineering Laboratory might offer an opportunity if it were financed on the same basis as the GERL or the Bell Laboratories. With adequate support, Alexanderson felt that the Engineering Laboratory might come to fill the same function in creative engineering that the other laboratories did in

science. He disputed the claim that the GERL facility was adequate for pioneering new systems noting that the scientists had enough to do without also taking responsibility for engineering research. He predicted that first rate engineers would be attracted to the Engineering Lab if they were assured of status and privileges comparable to those enjoyed by the GERL scientists. Alexanderson concluded that the rule of selection of engineers for the General Engineering Laboratory should be to "find the right man and he will create his own job."³⁵

IV

The nature of science and engineering and of the dynamic relationship between them have become major themes of historians of science and technology. The issue is of more than academic interest since corporate and public policy decisions involving the allocation of enormous resources have reflected particular perceptions of the relationship. The ideology that has dominated until recently has been called the "scientific ideology." This views engineering as being intellectually parasitic on science and having essentially no body of knowledge not borrowed from science.³⁶

A contrasting interpretation suggests that the relationship is actually more of a symmetric and symbiotic one in which both science and engineering possess distinct and cumulative bodies of knowledge.³⁷ In their persistent efforts to institutionalize creative engineering and achieve parity with the science-oriented laboratory at G.E., Steinmetz and Alexanderson were in effect challenging the sufficiency of the scientific ideology. It is interesting to find evidence of similar developments at the Bell Laboratories where Mervin J. Kelly articulated the concept of "organized creative technology" that included an autonomous Systems Engineering Department.³⁸

Historians of technology are beginning to give greater stress to the importance of noneconomic factors in technological development. Eugene Ferguson has pointed out in a recent paper that "if we fail to note the importance of enthusiasm that is evoked by technology, we will have missed a central motivating influence in technological development."³⁹ No one who reads the letterbooks and memoranda of Alexanderson would question the central importance of noneconomic incentives in engineering. The Consulting Engineering Department enabled him to be supported in his obsession with problem solving for more than forty years.

³⁵ Alexanderson to E. E. Johnson, Nov. 15, 1951, *AP*. Johnson had just been named to head the General Engineering Laboratory.

³⁶ E. T. Layton, Jr., "American ideologies of science and engineering," presented at a colloquium on the Interaction of Science and Technology in the Industrial Age in Mar. 1973 and to be published in *Technology and Culture* in 1976. See also Layton's "Technology as knowledge," *Technology and Culture*, vol. 15, pp. 31-41, 1974.

³⁷ *Ibid.*

³⁸ J. R. Pierce, "Mervin Joe Kelly," *Biographical Memoirs*, vol. 46. Washington, D.C.: Nat. Acad. Sci., 1975, pp. 190-219.

³⁹ E. S. Ferguson, "Toward a discipline of the history of technology," *Technology and Culture*, vol. 15, p. 21, 1974.

³¹ Transcript of A.S.M.E. speech, Nov. 30, 1942, *AP*.

³² Transcript of Edison Medal Speech dated Jan. 24, 1945, *AP*.

³³ Transcript of speech dated Nov. 7, 1945, *AP*.

³⁴ Transcript of speech given at the Technical University of Stockholm dated Oct. 7, 1948, *AP*.